

## Multi-Phase Fuel System

### FIELD OF THE INVENTION

The present invention relates to a multi-phase fuel system for internal combustion engines. More specifically, the system utilizes heat to separate a single fuel into high volatility, e.g. lower boiling temperature, components and low volatility components, e.g. higher boiling temperature. The high volatility components are delivered to the engine as a gaseous vapor containing the atomized lower volatility components. During combustion the highly volatile gaseous vapor promotes complete combustion of the lower volatility atomized components. In this manner the multi-phase fuel system is able to provide improved efficiency and reduced emissions throughout the entire range of engine requirements.

### BACKGROUND OF THE INVENTION

A fuel system is the component of an internal combustion engine which often has the greatest impact on performance and cost. Accordingly, fuel systems for internal combustion engines have received a significant portion of the total engineering effort expended to date on the development of the internal combustion engine. For this reason, today's engine designer has an extraordinary array of choices and possible permutations of known fuel system concepts and features.

1           Since the invention of the gasoline engine various  
2   attempts aimed at improving the efficiency of fuel systems have  
3   been made. Design effort typically involves extremely complex  
4   and subtle compromises among considerations such as cost, size,  
5   reliability, performance, ease of manufacture, and retrofit  
6   capability on existing engine designs. The challenge to  
7   contemporary designers has been significantly increased by the  
8   need to respond to government mandated emissions abatement  
9   standards while maintaining or improving fuel efficiency.

10           It is well known in the prior art to provide fuel in a  
11   liquid phase to a moving air stream for delivery to an internal  
12   combustion engine. Liquid fuel delivery systems, such as  
13   carburetors, were once standard for internal combustion  
14   engines. Carburetors use atomizing nozzles or jets which at  
15   least partially atomize the liquid fuel supplied to the engine.  
16   The nozzles aim the fuel at the throat of a venturi which, due  
17   to the sudden drop of pressure in the venturi, causes the  
18   liquid to break into small droplets of fuel. The small  
19   droplets of liquid fuel are then drawn into the cylinders of  
20   the engine for combustion.

21           Liquid phase fuel delivery systems, such as fuel  
22   injection, are the current standard for supplying liquid fuel  
23   to gasoline engines. Electrical pulses provided by the on-  
24   board computer cause the injectors to force liquid fuel through

1 a nozzle. The nozzle breaks up the liquid fuel into small  
2 droplets. Some injectors aim their spray at a venturi for  
3 further atomization, others directly inject their spray into  
4 the intake manifold or combustion chamber.

5 While fuel injectors are generally capable of atomizing  
6 liquid fuel better than a carburetor, they still deliver the  
7 fuel in a liquid phase as small droplets of fuel. Small  
8 droplets of fuel do not burn completely during combustion  
9 causing decreased engine efficiency and increased fuel  
10 consumption. In addition, the unburned fuel is discharged into  
11 the atmosphere as a pollutant.

12 Devices of the prior art have attempted to overcome the  
13 problems associated with liquid phase fuel delivery systems by  
14 vaporizing the liquid fuel supplied to the engine. Fuel  
15 vaporization can be accomplished in a number of ways, including  
16 various mechanical means such as screens or venturis. Other  
17 devices use heat to vaporize the liquid fuel. The prior art  
18 contains a substantial number of suggestions directed to  
19 vaporizing liquid fuels with heat for use in an internal  
20 combustion engine. These solutions have generally centered  
21 around using the exhaust gases of the engine as a source of  
22 heat for accomplishing vaporization.

23 When compared to an engine operating from liquid phase  
24 fuel, an engine operating on vaporized fuel offers increased

1 fuel economy and lower emissions. In their attempts to achieve  
2 maximum economy, the prior art has generally concentrated on  
3 operating an engine entirely on a vaporized liquid fuel such as  
4 gasoline. Because gasoline is comprised of a number of  
5 components which transform to a vapor phase at vastly different  
6 temperatures, there are a number of problems associated with  
7 vaporizing all of the components in sufficient quantities to  
8 supply a vehicle. The first such problem is an unavoidable  
9 delay associated with raising the temperature of the liquid  
10 fuel to a sufficient level to transform the fuel components  
11 with the highest boiling points to vapor. The delay adversely  
12 affects engine performance and causes poor throttle response.  
13 Numerous situations occur when operating a vehicle that require  
14 an immediate engine response time, e.g. accident avoidance and  
15 the like. While these situations only account for a small  
16 amount of total driving time, the delay associated with  
17 transforming the components of gasoline with the highest  
18 boiling temperatures to a vapor phase requires systems to be  
19 overbuilt or maintain a relatively large reserve supply of fuel  
20 vapor for acceptable operation. Overbuilt systems generally  
21 rely on excessive heat or large vaporizing apparatus to reduce  
22 response times. Reserve supplies of vaporized gasoline mixed  
23 with air are extremely volatile and may result in dangerous  
24 explosions.

1           A further problem associated with the overbuilt systems,  
2   that has not been adequately addressed by the prior art,  
3   involves the recognition that some gasoline components vaporize  
4   at about 95°F while others require temperatures above 425°F to  
5   completely vaporize. Overheating of the components with the  
6   lower boiling points may result in the formation of undesired  
7   gums and tars within the apparatus. Overheating the fuel also  
8   increases the risk of fire or explosion.

9           Still further problems exist with prior art systems which  
10   utilize sufficient heat to completely vaporize gasoline. When  
11   the incoming air is heated with the fuel, the heat  
12   significantly reduces air density thereby lowering the  
13   efficiency and power output of the engine. In addition, the  
14   highly heated air also results in an extremely dry air-fuel  
15   mixture. The dry air-fuel mixture does not provide adequate  
16   lubrication for the upper cylinder and the valve guides. This  
17   results in premature wear of the engine and significantly  
18   reduces its useful life.

19           Accordingly, what is lacking in the prior art is a cost  
20   effective multi-phase fuel system capable of separating the  
21   fuel into high volatility and low volatility components, and  
22   delivering the components to the engine in different phases to  
23   promote complete combustion and a lean air-fuel mixture. The  
24   multi-phase fuel system should achieve objectives such as

1 providing improved efficiency, quick response, reliable engine  
2 performance, and emissions abatement. The system should  
3 include packaging flexibility for installation on various  
4 engine configurations including retrofitting existing engines  
5 with minimal modification of the original fuel system.

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1 DESCRIPTION OF THE PRIOR ART

2 A number of prior art systems exist for completely  
3 vaporizing liquid fuel. Most of the systems utilize hot  
4 exhaust gases or electrical elements to achieve the high  
5 temperatures necessary to vaporize all of the fuel components,  
6 while others use a combination of both exhaust gas and  
7 electrical elements.

8 U.S. Patent No. 5,947,091 to Krohn et al. discloses a fuel  
9 injector having an internally mounted heating element. The  
10 device is aimed at reducing emissions during cold engine start  
11 and warm-up periods. During these periods fuel is vaporized as  
12 it passes through the injector and directly into the combustion  
13 chamber. The patent also discloses the possibility of  
14 continuous operation by directing hot exhaust gases through an  
15 optional gas channel that surrounds the body of the injector,  
16 but fails to disclose any method of controlling the heat within  
17 the device. As disclosed, this device is only capable of  
18 vaporizing liquid fuel during periods of low fuel flow to the  
19 engine. During high fuel flow the fuel would merely be heated  
20 before entering the combustion chamber. The patent fails to  
21 teach or suggest a fuel system capable of converting the lower  
22 boiling temperature components of gasoline into vapor,  
23 atomizing the higher boiling components, and supplying a  
24 combination of the two phases of fuel to the engine for a lean

1 burning mixture. In addition, this system requires the  
2 original fuel system to be removed from the vehicle.

3 U.S. Patent No.4,926,831 to Earl discloses a fuel  
4 vaporization apparatus in which fuel is completely vaporized  
5 before it enters the internal combustion engine. The liquid  
6 fuel is routed through two combination vaporization  
7 chamber/exhaust manifolds heated by exhaust gasses. The device  
8 is aimed at providing vaporized fuel for normal and heavy  
9 acceleration. A single heat exchange plate separates the  
10 vaporization chamber and the exhaust manifold. An electric  
11 fuel pump provides liquid fuel to foggers that spray fuel into  
12 the vapor chambers. An air pump provides air to the vapor  
13 chambers so that upon depression of the accelerator pedal the  
14 vaporized fuel will flow through the carburetor of the engine.  
15 The engine is started on liquid fuel, but after the vaporizing  
16 chamber reaches a preset temperature the liquid fuel system is  
17 shut off from the fuel supply. This system requires extensive  
18 modification of the vehicle engine compartment for  
19 installation. In addition, the thrust of the invention is  
20 vaporizing all components of the gasoline, therefore the device  
21 has all of the shortcomings associated therewith.

22 U.S. Patent Nos. 4,538,583, 4,622,944, and 4,665,879, also  
23 to Earl, disclose fuel vaporization apparatus in which the fuel  
24 vaporizes before it enters the internal combustion engine. The

1 engine is started on liquid fuel, but after the vaporizing  
2 chamber reaches a preset temperature the liquid fuel system is  
3 shut off from the fuel supply. After the vapor chamber reaches  
4 a temperature sufficient to vaporize all of the gasoline  
5 components, the liquid fuel is fed through various amounts and  
6 configurations of heat conductive tubing which is exposed to  
7 hot exhaust fumes and electrical heating elements. This design  
8 fails to control the temperature of the apparatus and must  
9 maintain reserve vapors for peak demands. Additionally, due to  
10 the location and volume of the fuel vapors, an engine backfire  
11 could result in a serious explosion.

12 U.S. Patent No. 4,606,319 to Silva discloses a dual fuel  
13 apparatus that operates entirely from gaseous and vaporized  
14 fuel. The engine is started on a primary fuel such as methane,  
15 hydrogen, natural gas, propane, butane or acetylene. When the  
16 exhaust reaches an adequate temperature gasoline is allowed to  
17 flow into a vaporization apparatus. The primary fuel mixes  
18 with the vaporized gasoline and pushes the mixed fuel vapors to  
19 the carburetor. This configuration would require significant  
20 modification to install the system on a vehicle that is  
21 currently equipped with a liquid fuel system.

22 U.S. Patent No. 4,161,931 to Giardini et al. discloses an  
23 exhaust gas heat exchanger for vaporizing liquid fuel. The  
24 engine is started using vaporized fuel stored in an accumulator

1 and thereafter uses the exhaust manifold to vaporize liquid  
2 fuel. The exhaust manifold consists of two generally parallel  
3 chambers and a diverter valve. Within one of the vaporizing  
4 chambers is a length of spirally wound heat conductive tubing.  
5 Liquid fuel is allowed to flow through the tube while the  
6 diverter valve controls the temperature within the tube-  
7 containing chamber. Vaporized fuel is stored in an accumulator  
8 before being supplied to the engine. This device recognizes  
9 that the temperature of the heat exchanger needs to be  
10 regulated. However, this system requires the use of complex  
11 servomechanisms and sensors. Due to its complexity, this  
12 device is not well suited for retrofitting on existing vehicles  
13 with gasoline engines. The configuration also requires a  
14 reserve supply of fuel vapor for peak demands, increasing the  
15 risk of explosion.

16 U.S. Patent No. 4,550,706 to Hoffman discloses a liquid  
17 fuel vaporization device. The device utilizes a plurality of  
18 elongated electrical elements mounted within the main air  
19 stream entering the engine. During warm-up or acceleration a  
20 thermostatically or mechanically controlled valve allows an air  
21 pump to deliver a pre-vaporized mixture of air and fuel into  
22 the venturi. After warm-up, liquid fuel is sprayed onto the  
23 elongated heating elements and vacuum from the engine draws the  
24 vaporized fuel mixture across the heated elements as it enters

1 the engine. This configuration holds a substantial amount of  
2 fuel vapor and air in an elongated air intake and does not  
3 disclose any means of containing the vaporized fuel within the  
4 device, thereby creating a significant risk of explosion. In  
5 addition, heating all of the air entering the engine to a  
6 sufficient temperature to completely vaporize gasoline lowers  
7 air density and significantly reduces engine performance.

8 U.S. Patent No. 4,151,821 to Witchman, deceased et al.,  
9 discloses an engine fuel system in which gas is vaporized in an  
10 atomization chamber prior to being fed into the internal  
11 combustion engine. An alternative gaseous fuel is used during  
12 start-up until the atomization chamber reaches a sufficient  
13 temperature to vaporize gasoline. After warm-up, liquid fuel  
14 is sprayed by jet nozzles against a metal plate which is heated  
15 by exhaust gases. The resulting vaporized gasoline is then  
16 supplied to a carburetor.

17 U. S. Patent No. 6,119,637 to Matthews et al., discloses  
18 a coolant heated on-board gasoline distillation system for  
19 reduced emissions at start-up. The device partially vaporizes  
20 the engine's primary fuel. The vaporized components are then  
21 re-condensed to a liquid and transferred to a second fuel tank.  
22 During initial start-up of the engine the secondary fuel is  
23 allowed to flow through the standard liquid fuel delivery  
24 system, e.g. carburetor or fuel injection. After start-up the

1 secondary fuel is shut off and the primary fuel is consumed.  
2 This type of system offers reduced emissions during the short  
3 warm-up cycle of the engine. However, the primary fuel  
4 consumed after warm-up combusts poorly, causing spark knock and  
5 increased emissions.

6 The prior art devices fail to teach or suggest the use of  
7 a system capable of separating the components of a liquid fuel,  
8 e.g. gasoline, and delivering them to the engine in at least  
9 two different phases to enhance combustion and reduce  
10 emissions. The prior art is also deficient in teaching a fuel  
11 vaporization system that does not detrimentally affect air  
12 density. The references are further deficient in teaching a  
13 multi-phase fuel system that can be easily installed on new, as  
14 well as existing, engines with minimal modification of the  
15 original fuel system.

1     **SUMMARY OF THE INVENTION**

2           The present invention provides a multi-phase fuel system  
3     for an internal combustion engine. More specifically, when the  
4     multi-phase fuel system is applied to a vehicle, the higher  
5     volatility (lower boiling temperature) components of fuel are  
6     supplied to the engine in a gaseous vapor form while the lower  
7     volatility (higher boiling temperature) components of fuel are  
8     supplied to the engine in an atomized form. In this manner,  
9     the multi-phase fuel system is capable of providing a more  
10    optimum lean air/fuel mixture for better fuel economy and  
11    emissions control during normal operating conditions while  
12    being able to quickly enrich the fuel mixture in response to  
13    sudden increases in load demand.

14          The liquid fuel is generally hydrocarbon fuel, such as  
15    gasoline, which is typically comprised of various components  
16    such as Pentane, Hexane, Heptane, Octane, Nonane, Decane and  
17    Hendacane. These components vaporize at temperatures that  
18    range between 95°F and 450°F. It is well known in the art that  
19    the components of gasoline with the lowest boiling points  
20    generate lower emissions and higher gas milage per unit than  
21    the components with higher boiling points. The instant  
22    invention is constructed and arranged to vaporize the higher  
23    volatility components of the fuel and use the highly volatile  
24    gaseous vapor to promote combustion of the atomized lower

1 volatility fuel components. When compared to systems that  
2 concentrate on vaporizing all of the liquid fuel, the lower  
3 temperatures required by the instant invention allow the  
4 reformer fuel system to react faster to engine demands, thereby  
5 eliminating the lag normally associated with total vapor fuel  
6 systems.

7 The multi-phase fuel system generally comprises a  
8 canister, at least one fuel injector, at least one heating  
9 element, a fuel supply, a fuel pressure regulator, an optional  
10 fresh air control means, and an optional gas mixer.

11 In a preferred embodiment the canister is generally a  
12 heavy walled tube including a first open end constructed and  
13 arranged as an air intake, and a second end constructed and  
14 arranged to cooperate with a throttle body of a fuel injection  
15 system. The sidewall of the canister is generally constructed  
16 to provide support for at least one electric fuel injector and  
17 at least one electric heating element. The sidewall of the  
18 canister may also be configured to provide support for the  
19 optional air control means and the fuel regulator. The heating  
20 element(s) are arranged within the bore of the tube to be in  
21 the direct path of the atomized fuel discharged from the fuel  
22 injector. Air flowing through the canister bore carries the  
23 gaseous fuel, atomized fuel and fresh air mixture into the  
24 engine for combustion.

1           In a second embodiment the canister is generally a heavy  
2   walled tube having a first end with an aperture constructed and  
3   arranged to cooperate with at least one electric fuel injector,  
4   and a second end constructed and arranged to cooperate with an  
5   air-gas mixing device. The sidewall of the canister is  
6   generally constructed to provide support for at least one  
7   electrical heating element and at least one fresh air control  
8   means. The heating element(s) are arranged within the bore of  
9   the tube to be in the direct path of the fuel and air flowing  
10  through the canister's reformer chamber. During operation a  
11  small amount of fresh air is drawn through the air valve means  
12  into the bore of the canister. The fresh air mixes with the  
13  multi-phase fuel and the air-gas mixer allows the mixture to  
14  flow to the engine based on demand.

15           The construction of the systems allow the engine to be  
16  cold started directly with either a multi-phase fuel system or  
17  the factory installed fuel injection system. When the engine  
18  is operated using one of the multi-phase fuel systems, electric  
19  current is allowed to flow from the battery through the heating  
20  element(s) to raise the temperature within the canister to  
21  about 250°F. The vehicle's on-board computer operatively  
22  controls the fuel injector(s) to spray liquid fuel into the  
23  bore of the canister. The fuel injector finely atomizes the  
24  liquid gasoline and directs it across the electrical heating  
25  element(s). Since the heating element(s) maintain the

1 temperature of the reformer chamber at a temperature of, for  
2 example 250°F., and since the liquid gasoline consists of  
3 various mixtures of gasoline components which vaporize within  
4 a range of 95°F. for Pentane to about 450°F. for Hendacane, the  
5 higher volatility (low boiling temperature) components of the  
6 gasoline will vaporize as the gasoline flows through the  
7 canister, while the lower volatility (higher boiling  
8 temperature) fuel will remain in an atomized state.

9 As engine vacuum draws fresh air through the normal air  
10 intake passage, a small amount of incoming air may be allowed  
11 to flow through the air control means, preferably a check  
12 valve, into the canister. The fresh air entering the canister  
13 mixes with the vaporized and atomized fuel and then flows out  
14 of the canister to mix with the primary incoming air, and may  
15 flow through an optional air-gas mixer before flowing to the  
16 engine for combustion.

17 In this manner the air control means blocks the intake  
18 orifice to prevent the air/fuel mixture from flowing out of  
19 the vapor canister and into the engine compartment, but allows  
20 air to flow into the canister to push the air/fuel mixture to  
21 the engine when the pressure differential across the check-  
22 valve is sufficient to overcome the check valve.

23 The multi-phase fuel system can thereby provide improved  
24 fuel economy and reduced emissions over vehicles operating  
25 entirely from liquid fuel or from completely vaporized fuel.

1 The system can also provide immediate throttle response that  
2 vapor only systems cannot provide without maintaining a  
3 relatively large amount of reserve vaporized fuel. This system  
4 also offers improved safety by not allowing fuel vapor to  
5 escape from the system into the engine compartment.

6 Accordingly, it is an objective of the present invention  
7 to provide a fuel system capable of separating the components  
8 of a single fuel, e.g. gasoline, and delivering them to the  
9 engine in at least two different phases to enhance combustion  
10 and reduce emissions.

11 Yet an additional objective of the present invention is to  
12 provide a fuel system capable of providing a combination of  
13 vaporized high volatility (lower boiling temperature) fuel and  
14 atomized lower volatility (higher boiling temperature) fuel  
15 based on engine demands that requires minimal modifications to  
16 the factory fuel system.

17 It is a further objective of the present invention to  
18 provide a fuel system capable of providing a combination of  
19 vaporized high volatility (lower boiling temperature) fuel and  
20 atomized lower volatility (higher boiling temperature) fuel  
21 based on engine demands that eliminates the need to store  
22 excessive amounts of vaporized fuel.

23 A still further objective of the present invention is to  
24 provide a fuel system capable of providing a combination of  
25 vaporized high volatility (lower boiling temperature) fuel and

1 atomized lower volatility (higher boiling temperature) fuel  
2 based on engine demands that can be installed on existing as  
3 well as new vehicles.

4 Another objective of the present invention is to provide  
5 a kit for a fuel system capable of separating the components of  
6 a single fuel, e.g. gasoline, and delivering them to the engine  
7 in at least two different phases to enhance combustion and  
8 reduce emissions based on engine demands which is simple to  
9 install and which is ideally suited for original equipment and  
10 aftermarket installations.

11 Yet another objective of the present invention is to  
12 provide a kit for a fuel system capable of providing a  
13 combination of vaporized high volatility (lower boiling  
14 temperature) fuel and atomized lower volatility (higher boiling  
15 temperature) fuel based on engine demands that can be  
16 inexpensively manufactured and which is simple and reliable in  
17 operation.

18 Still another objective of this invention is to provide a  
19 method of separating a single fuel into its higher volatility  
20 and lower volatility components and delivering them to the  
21 engine in at least two different phases to enhance combustion  
22 and reduce emissions.

23 Other objects and advantages of this invention will become  
24 apparent from the following description taken in conjunction  
25 with the accompanying drawings wherein are set forth, by way of

1 illustration and example, certain embodiments of this  
2 invention. The drawings constitute a part of this  
3 specification and include exemplary embodiments of the present  
4 invention and illustrate various objects and features thereof.

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1 BRIEF DESCRIPTION OF THE FIGURES

2 Figure 1 is a schematic representation illustrating one  
3 embodiment of the multi phase fuel system of the present  
4 invention;

5 Figure 2 is a section view illustrating one embodiment of  
6 the canister assembly of the present invention;

7 Figure 3 is a schematic representation illustrating an  
8 alternative embodiment of the multi phase fuel system of the  
9 present invention;

10 Figure 4 is a section view illustrating an alternative  
11 embodiment of the canister assembly of the present invention;

12 Figure 5 is a chart illustrating milage tests performed on  
13 the present invention.

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1 DETAILED DESCRIPTION OF THE INVENTION

2 Although the invention is described in terms of a  
3 preferred specific embodiment, it will be readily apparent to  
4 those skilled in this art that various modifications,  
5 rearrangements and substitutions can be made without departing  
6 from the spirit of the invention. The scope of the invention  
7 is defined by the claims appended hereto.

8 In order to alleviate the problems associated with  
9 operating an internal combustion engine entirely from liquid  
10 fuel or entirely from vaporized liquid fuel, the present  
11 invention utilizes a multi-phase fuel system 100 as set forth  
12 in Figure 1. The multi-phase fuel system separates the  
13 components of a single fuel, e.g. gasoline, and delivers the  
14 higher volatility (lower boiling temperature) components of the  
15 fuel to the engine 34 in a gaseous vaporized form while the  
16 lower volatility (higher boiling temperature) components of the  
17 fuel are supplied to the engine in an atomized form. The  
18 multi-phase fuel system is capable of providing a more optimum  
19 lean air/fuel mixture for better fuel economy and emissions  
20 control during normal operating conditions while being able to  
21 quickly enrich the fuel mixture in response to sudden increases  
22 in load demand.

23 In accordance with Figures 1 and 2, a preferred embodiment  
24 is illustrated installed on a typical internal combustion  
25 engine 34 having a plurality of electric fuel injectors 36

1     operatively controlled by an on board computer 38. The multi-  
2     phase fuel system 100 generally includes a means for supplying  
3     a mixture of vaporized lower temperature boiling components of  
4     fuel and atomized higher temperature boiling components of  
5     gasoline to an engine illustrated herein as a canister assembly  
6     10 and an optional gas mixer 6 (FIG.3). The multi-phase fuel  
7     system components are constructed and arranged to be installed  
8     and operated either as a fuel system parallel to the standard  
9     fuel injection or as a stand alone fuel system for an internal  
10    combustion engine. When operated as a parallel system, the  
11    reformer fuel system is generally adapted to utilize the  
12    vehicle's existing liquid fuel supply 4, fuel pump 39,  
13    electrical supply 8, on board computer 38, and throttle plate  
14    40. A fuel diverter valve 41 may be utilized for routing the  
15    liquid fuel between the multi-phase fuel system 100 and the  
16    factory installed injector system 36. The diverter valve 41  
17    may be operated by a manual switch 42 or may be automatically  
18    operated by the vehicle's ignition switch or on board computer  
19    using suitable electrical devices well known in the art. The  
20    multi-phase fuel system 100 may also be provided with a manual  
21    switch 44 for allowing electrical current to flow to the  
22    heating element means 18 and a manual switch 46 for allowing  
23    electrical signals to reach the fuel modulating means 14.  
24    These switches may also be automatically operated by the  
25    vehicle's ignition switch or on board computer using suitable

1     electrical devices well known in the art. In this manner, the  
2     multi-phase fuel system 100 can be configured to allow the  
3     vehicle's operator to choose between operating the engine with  
4     the multi-phase fuel system 100 or the standard liquid fuel  
5     injection delivery system. Alternatively, the multi-phase fuel  
6     system 100 can be configured to be the primary fuel delivery  
7     system, wherein the system initiates during the engine starting  
8     cycle. Referring to FIG. 2, the canister assembly 10 of the  
9     multi-phase fuel system 100 is illustrated. The canister  
10    assembly 10 generally includes at least one fuel injector 14,  
11    at least one heating element 18, at least one fresh air control  
12    means 20, and an optional fuel pressure regulator 22.

13       The canister 2 is generally comprised of a thick walled  
14    tube having a first end 13 constructed and arranged as a fresh  
15    air intake and a second end 12 constructed and arranged to  
16    cooperate with the throttle body of a fuel injected engine  
17    (FIG.1). The canister 2 forms an enclosure surrounding the  
18    interior bore 16. In the preferred embodiment the volume of  
19    interior bore 16 is approximately 1.75 cubic inches. Larger or  
20    smaller bores may also be utilized on engines with large or  
21    small displacements, with the optimum size bore being  
22    determined by routine experimentation. The canister 2 is  
23    preferably constructed of aluminum, but may be constructed of  
24    other suitable materials well-known in the art which are  
25    capable of withstanding contact with fuel and capable of

adequate heat resistance. As an alternative embodiment, the canister 2 may have at least one insulating layer of a suitable material well known in the art covering or at least partially covering the surface of the canister.

Removably mounted in the side wall of canister 2 are a plurality of generally concentric bores arranged for removably attaching and locating a fuel injector 14, and at least one, and preferably two, heating element means, illustrated herein as electric glow plugs 18 for heating the interior bore 16 of the canister 2. The heating element means should be capable of maintaining the temperature of the canister bore preferably at about 250° F. Devices such as resistors, rectifier bridges, potentiometers or other suitable devices well known in the art may be used for operational control of the heating elements. Such devices may also incorporate a separate temperature sensor and/or function in concert with the on-board computer 38 to control the heating element(s) in order to maintain the temperature within the canister bore 16. At least one fuel injector 14 is removably attached within the concentric bores located within the side of the canister 2. The at least one fuel injector is preferably a high performance and high volume electric fuel injector capable of modulating an adequate amount of fuel to the canister bore 16 for efficient operation of the engine 34. Such a fuel injector is currently manufactured by Ford Motor Company and is being used for racing applications.

1 The fuel injector is preferably wired, via connector 48, to  
2 receive electrical signals from the on-board computer 38 in  
3 parallel with the number one cylinder 50, but may be wired to  
4 receive electrical signals in parallel with any suitable  
5 cylinder. In this manner the on board computer 38 can utilize  
6 various sensors, standard to the vehicle, to monitor the  
7 engines 34 operating parameters for operational control of the  
8 fuel injector(s) 14. The fuel injector 14 is preferably  
9 provided with a liquid fuel regulating means which is in fluid  
10 communication with the liquid fuel supply 4 via fuel conduit 5.  
11 The fuel regulating means is illustrated herein as a fuel  
12 pressure regulator 22 controlled by engine vacuum supplied  
13 through vacuum conduit 26 (FIG. 1) which is preferably in fluid  
14 communication with the engine's intake manifold. The fuel  
15 pressure regulator 22 is adapted to mate with the fuel injector  
16 14 and the fuel rail 28 (FIG. 1) via the regulator block 30 and  
17 thereby control the pressure of liquid fuel delivered to the  
18 fuel injector 14, returning unused liquid fuel to the tank via  
19 line 7 (FIG. 1). Other suitable devices well known in the art  
20 that are capable of delivering a relatively constant pressure  
21 or volume of liquid fuel could be used as a liquid fuel  
22 regulating means.

23 Also removably mounted in the side wall of the canister 2  
24 is the optional air inlet control means illustrated herein as  
25 a check valve 20 having an aperture 32 passing therethrough in

1 fluid communication with fresh air and the canister bore 16.  
2 The check valve 20 allows fresh air to enter the canister bore  
3 16 when the pressure differential across the check-valve is  
4 sufficient to overcome the check valve spring (not shown). The  
5 check valve 20 preferably opens when the pressure differential  
6 is about one pound per square inch, but may be more or less  
7 depending on the desired fuel intake characteristics and can be  
8 determined by routine experimentation. The diameter of the  
9 aperture is preferably about 3/8 inches, but the optimum size  
10 may vary based on engine displacement and should be determined  
11 by routine experimentation. In this manner the check-valve 20  
12 blocks the intake aperture 32 to prevent the air/fuel mixture  
13 from flowing out of the canister bore 16 and into the engine  
14 compartment, but allows air to flow into the canister bore to  
15 push the air/fuel mixture to the engine 34. Alternatively, air  
16 may be injected into the canister by devices and/or methods  
17 well known in the art that are capable of delivering a  
18 controlled amount of air to the canister bore.

19 Provided in the second end 12 of the canister 2 is a air-  
20 fuel outlet 24 in fluid communication with the engine's  
21 throttle body 40. The throttle body 40 is constructed and  
22 arranged to allow the air/fuel mixture from the canister bore  
23 16 to enter and mix with the engine's incoming airstream.  
24 Other suitable devices well known in the art that are capable  
25 of mixing the air/fuel mixture from the canister bore 16 with

1 the incoming airstream of the engine may also be utilized. The  
2 canister 2 is preferably constructed and arranged to be  
3 removably and sealably attached to the throttle body 40.  
4 Alternatively, the canister 2 and the throttle body 40 may be  
5 constructed as a single unitary piece.

6 Referring to FIGS. 3 and 4, an alternative embodiment of  
7 the multi-phase fuel system 200 and canister assembly 210 is  
8 illustrated. The alternative embodiment canister assembly 210  
9 generally includes at least one fuel injector 14, at least one  
10 heating element 18, at least one fresh air control means 20,  
11 and an optional fuel pressure regulator 22.

12 The canister 202 is generally comprised of a thick walled  
13 tube having a first end 213 constructed and arranged with a  
14 plurality of centrally located bores arranged for removably  
15 attaching and locating a fuel injector 14, and a second end 212  
16 constructed and arranged to cooperate with an air-gas mixer 6  
17 (FIG.3). The canister 202 forms a sealed enclosure surrounding  
18 the canister bore 16. In the preferred embodiment the volume  
19 of canister bore 16 is approximately 1.75 cubic inches. Larger  
20 or smaller bores may also be utilized on engines with large or  
21 small displacements, with the optimum size of canister bore  
22 being determined by routine experimentation. The canister 202  
23 is preferably constructed of aluminum, but may be constructed  
24 of other suitable materials well-known in the art which are  
25 capable of withstanding contact with fuel and capable of

1 adequate heat resistance. As an alternative embodiment the  
2 canister 202 may have at least one insulating layer of a  
3 suitable material well known in the art covering or at least  
4 partially covering the surface of the canister.

5 Removably mounted in the side wall of canister 202 is at  
6 least one, and preferably two, heating element means,  
7 illustrated herein as electric glow plugs 18 for heating the  
8 canister bore 16 of the canister 202. The heating element means  
9 should be capable of maintaining the temperature of the  
10 canister bore preferably at about 250° F. Devices such as  
11 resistors, rectifier bridges, potentiometers or other suitable  
12 devices or methods well known in the art may be used for  
13 operational control of the heating elements. Such devices may  
14 also incorporate a temperature sensor and/or the on-board  
15 computer 38 to control the heating element(s) in order to  
16 maintain the temperature within the canister bore 16.

17 At least one fuel injector 14 is removably attached within  
18 the centrally located bores of the first end 213 of the  
19 canister 202. The fuel injector is preferably a high  
20 performance and high volume electric fuel injector capable of  
21 modulating an adequate amount of fuel to the canister bore 16  
22 for efficient operation of the engine 34. Such a fuel injector  
23 is currently manufactured by Ford Motor Company and is being  
24 used for racing applications. The fuel injector is preferably  
25 wired, via connector 48 to receive electrical signals from the

1 on-board computer 38 in parallel with the number one cylinder  
2 50, but may be wired to receive electrical signals in parallel  
3 with any suitable cylinder. In this manner the on board  
4 computer 38 can utilize various sensors, standard to the  
5 vehicle, to monitor the engines 34 operating parameters for  
6 operational control of the fuel injector(s) 14. The fuel  
7 injector 14 is preferably provided with a liquid fuel  
8 regulating means which is in fluid communication with the  
9 liquid fuel supply 4 via fuel conduit 5. The fuel regulating  
10 means is illustrated herein as a fuel pressure regulator 22  
11 controlled by engine vacuum supplied through vacuum conduit 26  
12 which is preferably in fluid communication with the engine's  
13 intake manifold. The fuel pressure regulator 22 is adapted to  
14 mate with the fuel injector 14 and the fuel rail 28 via the  
15 regulator block 30 and thereby control the pressure of liquid  
16 fuel delivered to the fuel injector 14. Other suitable devices  
17 well known in the art that are capable of delivering a  
18 relatively constant pressure or volume of liquid fuel could be  
19 used as a liquid fuel regulating means.

20 Also in the side wall of the canister 202 is the air inlet  
21 control means illustrated herein as a check valve 20 having an  
22 aperture 32 passing therethrough in fluid communication with  
23 fresh air and the canister bore 16. The check valve 20 allows  
24 fresh air to enter the canister bore 16 when the pressure  
25 differential across the check-valve is sufficient to overcome

1 the check valve spring. The check valve 20 preferably opens  
2 when the pressure differential is about one pound per square  
3 inch but may be more or less depending on the desired fuel  
4 intake characteristics and can be determined by routine  
5 experimentation. The diameter of the aperture is preferably  
6 about 3/8 inches, but the optimum size may vary based on engine  
7 displacement and should be determined by routine  
8 experimentation. In this manner the check-valve 20 blocks the  
9 intake aperture 32 to prevent the air/fuel mixture from flowing  
10 out of the canister bore 16 and into the engine compartment,  
11 but allows air to flow into the canister bore to push the  
12 air/fuel mixture to the engine 34.

13        Provided in the second end 212 of the canister 202 is a  
14 air-fuel outlet 224 in fluid communication with the fuel mixer  
15 6 (FIG. 3). The fuel mixer 6 is constructed and arranged to  
16 allow the air/fuel mixture from the canister bore 16 to enter  
17 and mix with the engine's incoming airstream. Such a fuel  
18 mixer is currently manufactured by Impco Carburetion Inc. of  
19 Cerritos, California. Other suitable devices well known in the  
20 art that are capable of mixing the air/fuel mixture from the  
21 canister bore 16 with the incoming airstream of the engine may  
22 also be utilized. Such devices may include but should not be  
23 limited to plunger valves, reed valves, solenoid valves, rotary  
24 valves and the like. In a preferred embodiment the gas mixer  
25 should be constructed and arranged to substantially prevent the

1 escape of residual vaporized fuel into the engine compartment  
2 area of the vehicle after the engine is shut off. The canister  
3 202 is preferably constructed and arranged to be removably and  
4 sealably attached to the fuel mixer 6. Alternatively, the  
5 canister 202 and the fuel mixer 6 may be constructed as a  
6 single unitary piece.

7 In an alternative non-limiting embodiment the side wall of  
8 the canister 202 may include a removably mounted sensor (not  
9 shown) for monitoring the temperature of the canister bore 16.  
10 The temperature sensor should be capable of communication with  
11 the vehicle's on-board computer 38. In this embodiment the  
12 vehicle's on-board computer is capable of operational control  
13 of the glow plug(s) 18 based on communication from the  
14 temperature sensor to maintain the desired temperature within  
15 the canister bore 16.

16 In Figure 5, a representative portion of comparative road  
17 tests are illustrated wherein the Multi-phase Fuel System was  
18 installed on a 1999 Ford Expedition with a 5.4 liter engine  
19 having fuel injection. The tests were conducted in consecutive  
20 series by filling the fuel tank with 89 octane gasoline,  
21 driving the vehicle a predetermined number of miles, and again  
22 refilling the tank to establish the quantity of fuel consumed  
23 for the distance traveled, thereby effectively eliminating any  
24 errors attributed to differences in filling characteristics at  
25 filling stations. Typically the vehicle was driven along a

1 predetermined course utilizing the reformer fuel system and  
2 returned along the same predetermined course utilizing the  
3 factory fuel injection system for a direct comparison of the  
4 two systems. The milage traveled and the quantity of fuel  
5 consumed were thereafter recorded with remarks for conditions  
6 encountered.

7 Comparison tests were conducted over a distance of about  
8 13,000 miles with approximately half of the miles driven  
9 utilizing the multi-phase fuel system and approximately half of  
10 the miles driven using the factory original fuel injection  
11 system. Test conditions varied with temperatures ranging  
12 between 19° F. and 90° F.; heavy winds and heavy rains were  
13 also encountered. Over the complete series of tests, with city  
14 and highway driving combined, the vehicle averaged about 44.54  
15 mpg using the Reformer Fuel System and 18.50 mpg using the  
16 factory installed fuel injection system.

17 All patents and publications mentioned in this  
18 specification are indicative of the levels of those skilled in  
19 the art to which the invention pertains. All patents and  
20 publications are herein incorporated by reference to the same  
21 extent as if each individual publication was specifically and  
22 individually indicated to be incorporated by reference.

23 It is to be understood that while a certain form of the  
24 invention is illustrated, it is not to be limited to the  
25 specific form or arrangement herein described and shown. It

1 will be apparent to those skilled in the art that various  
2 changes may be made without departing from the scope of the  
3 invention and the invention is not to be considered limited to  
4 what is shown and described in the specification.

5 One skilled in the art will readily appreciate that the  
6 present invention is well adapted to carry out the objectives  
7 and obtain the ends and advantages mentioned, as well as those  
8 inherent therein. The embodiments, methods, procedures and  
9 techniques described herein are presently representative of the  
10 preferred embodiments, are intended to be exemplary and are not  
11 intended as limitations on the scope. Changes therein and other  
12 uses will occur to those skilled in the art which are  
13 encompassed within the spirit of the invention and are defined  
14 by the scope of the appended claims. Although the invention  
15 has been described in connection with specific preferred  
16 embodiments, it should be understood that the invention as  
17 claimed should not be unduly limited to such specific  
18 embodiments. Indeed, various modifications of the described  
19 modes for carrying out the invention which are obvious to those  
20 skilled in the art are intended to be within the scope of the  
21 following claims.

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